

Observation of Antiferromagnetic Domains in Epitaxial Thin Films

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INTRODUCTION

The current interest in magnetic multilayers is driven by the interesting physics as well as by their application in the magnetic-storage industry [1]. An important and scientifically challenging class of materials are antiferromagnetic (AFM) thin films, because of their use in exchange bias applications [2]. Exchange bias is referred to the effect of aligning (pinning) the magnetization direction of a ferromagnet by coupling it to an AFM. This effect is routinely used in the manufacturing of advanced magnetic recording heads and it will be used in tomorrow's non-volatile magnetic memory devices. The existence of the exchange bias phenomenon has been known for more than 45 years, but the origin of this effect remains an active research area as recently reviewed by Nogués and Schuller [2]. This technologically important effect is still poorly understood because of the inability of traditional techniques to spatially determine the microscopic magnetic structure of the AFM thin film. Here we demonstrate [3] the ability of x-ray spectromicroscopy to image the magnetic structure of AFM thin films with high spatial resolution using the photoelectron emission microscope (PEEM-II) located at beam line 7.3.1.1 of the Advanced Light Source (ALS) [4].

EXPERIMENT

PEEM is a full field imaging technique where x-ray excited electrons are used to form an image of the sample surface as a function of the x-ray photon energy and polarization. This so called spectromicroscopy method combines two concepts: X-ray absorption spectroscopy and electron microscopy. Contrast can be due to a number of mechanisms including topographical, elemental, chemical, polarization, magnetic linear and circular dichroism.

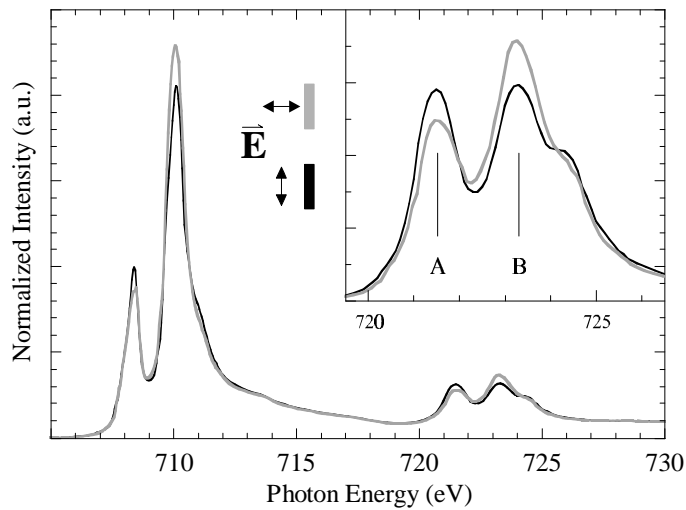


Figure 1 Total electron yield Fe L-edge XMLD spectra for a 26 nm thick film of LaFeO₃ grown on SrTiO₃(100).

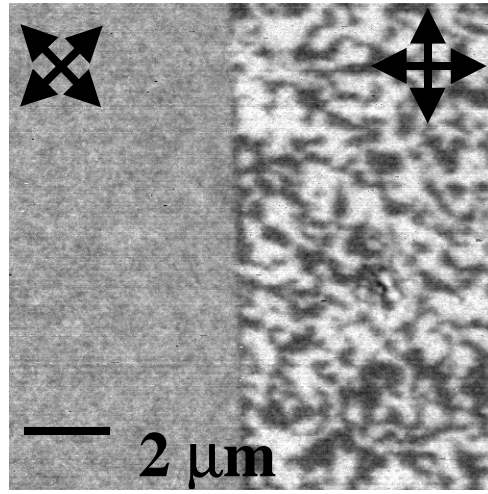


Figure 2. Image of the bicrystal junction taken with the PEEM. Arrows indicate the orientation of the crystallographic c-axis. Photon polarization E is horizontal.

The sample studied was a thin 40 nm LaFeO_3 film deposited on an asymmetric SrTiO_3 (100) bicrystal where two (100) crystals were joined macroscopically at (110) and (010) faces, leading to a 45° rotation of the lattice around the surface normal. Using linearly polarized light, the angle dependent XMLD effect was measured, see Figure 1, which is due to a preferential orientation of the antiferromagnetic axis \vec{A} . In particular, peak A at 721.5 eV is larger than peak B at 723.2 eV if the polarization of the x-ray \vec{E} is perpendicular to \vec{A} and smaller for \vec{E} parallel to it. In order to image the AFM structure of the LaFeO_3 surface we took images at 723.2 eV (peak B) and at 721.5 eV (peak A) and divided them. The resultant image (Figure 2) produces antiferromagnetic contrast and eliminates topographic contrast. The image was taken at the bicrystal junction, and reveals striking AFM domains on the right side of the junction and a uniform gray shade on the left side. The strong magnetic contrast on the right side arises from magnetic domains with an in-plane projection of \vec{A} parallel (white) and perpendicular (black) to the horizontal \vec{E} vector. On the left side the domains cannot be distinguished since \vec{E} has an equal 45° projection onto the two orientations of \vec{A} . Since in our experimental geometry \vec{E} lies in the surface plane we cannot distinguish domains whose axis \vec{A} is rotated by 180° about the surface normal. Thus we only observe two of the four antiferromagnetic domains that have to exist by symmetry.

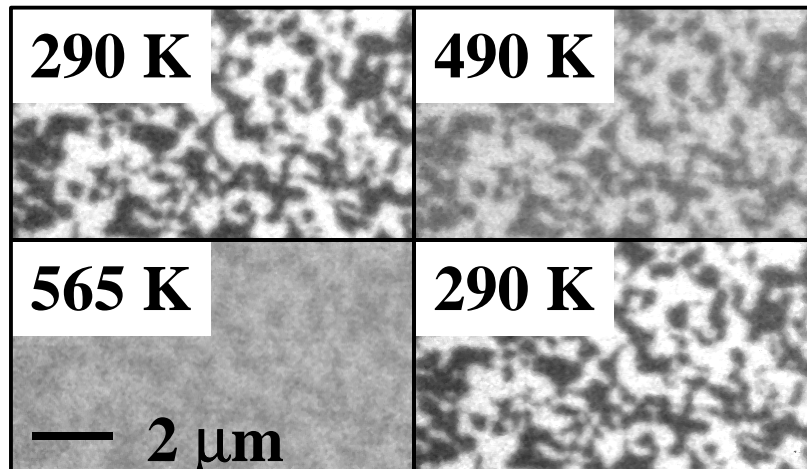


Figure 3. Temperature dependence of the antiferromagnetic domain contrast.

The temperature dependence of the XMLD effect was measured between 290 K and 550 K. The image contrast (see Figure 3) is strongly reduced at elevated temperatures and it is completely reversible upon cooling to room temperature, indication that, within the studied temperature range, the magnetic state of the sample is not affected by chemical or diffusive processes at the sample surface. By a quantitative analysis of the XMLD image contrast a Néel temperature of $T_N = (670 \pm 10)$ K was found for the film [3]. This value is reduced compared to that of the bulk LaFeO_3 , with $T_N = 740$ K [5]. The reduced Néel temperature is unlikely due to a finite size effect. Instead, we attribute the reduced Néel Temperature to epitaxial strain.

PEEM spectromicroscopy is shown to provide the necessary resolution and contrast to resolve the generally small antiferromagnetic domains in thin films. Our studies further open the door for combined linear and circular dichroism studies of the magnetic structure at ferromagnetic-antiferromagnetic interfaces, so-called exchange bias systems, that are both scientifically challenging and technologically important.

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This work was supported by the Division of Chemical Sciences (SSRL) and the Division of Materials Science (ALS) of the Office of Basic Energy Sciences of the U.S. Department of Energy. J.W.S and F.N. acknowledge support by the Swiss National Science Foundation.

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